Supplementary material

Appendix 1: Significance and consistency of species responses to temperature and predictive performance of models, for all 25 species under study.

Appendix 2: Methods for the assessment of significance and consistency of temperature-only and all-predictors quantile regression models.

Appendix 3: Representation of temperature-only models and all-predictors models for all 25 species under study.

Appendix 4: Visual comparison of predictive performance of temperature-only and all-predictors models, respectively, for all 25 species under study.

Appendix 5: Maximum potential abundance predicted across the temperature sum gradient and its geographical projection in Finland for 1985 and 2040-2070 warming scenario, for 15 species with significant and consistent responses.

Appendix 6: Latitudinal shift of species maximum potential abundance predicted from 1985 to 2040-2070 in Finland, under IPCC scenario A1B.

Appendix 7: Partial effects of all environmental factors considered in the study on the maximum potential abundance of the 25 species.
Appendix 1: Significance and consistency of species responses to temperature and predictive performance of models, for all 25 plant species under study. Temperature-only models (T-only) are 95% quantile regression models including only effective temperature sum as predictor, while all-predictors models (All-p) include effective temperature sum, cumulative precipitation, soil texture, soil fertility, stand basal area and proportion of deciduous tree species as predictors. Prevalence: number of plots with positive abundance in 1985. L: measure of predictive performance based on the check loss function; lower values of L mean a better predictive capacity (see methods). Significance: whether the effect of effective temperature sum on maximum potential abundance is significant (x) or not (white space) in T-only and All-p models, considering 95% intervals (see Appendix S2 and S3). Consistency: whether the trend of the response of species maximum potential abundance to effective temperature sum is consistent (x) or not (white space) between T-only and All-p models, considering 95% intervals (see Appendix 2 and 3). Consistency of results is only analyzed when the response to effective temperature sum is significant in both T-only and All-p models. Species that show a significant response to effective temperature sum in both T-only and All-p models and a consistent response between them are selected for forecasting and highlighted in bold.
<table>
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<th>Plant group</th>
<th>Prevalence</th>
<th>$L$</th>
<th>Significance</th>
<th>Consistency</th>
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<td>$All\text{-}p$</td>
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<td>Vaccinium vitis-idaea</td>
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<td>0.131</td>
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Appendix 2: Methods for the assessment of significance and consistency of temperature-only and all-predictors quantile regression models.

Response to temperature was considered insignificant, if it was possible to fit a horizontal line of constant response over the range of effective temperature sums included in our data within the estimated 95% confidence intervals. In such cases, our model does not provide statistically significant evidence against the null hypothesis of “no response to temperature”. Technically, this was checked by assessing, whether the maximum of the lower limits, \( l(T) \), of 95% confidence intervals was smaller than the minimum of the upper limits \( u(T) \) (Fig. A2-1a). Thus, response to temperature was considered significant if \( l(T^-) > u(T^+) \), where \( T^- \) is the temperature value that maximizes \( l \) and \( T^+ \) the one that minimizes \( u \). This implies that pairs of temperature sum values can be found, for which the confidence intervals of the predicted maximum potential abundance do not overlap (Fig. A2-1b).

Figure A2-1. Examples of models with insignificant and significant response to temperature. a) Temperature-only model for Calluna vulgaris, illustrating maximum \( l(T^-) \), of the lower limits of 95% confidence intervals (dashed line) and the minimum \( u(T^+) \) of the upper limits (dotted line). Response of C. vulgaris to temperature was considered insignificant, because \( u(T^+) > l(T^-) \). b) Temperature-only model for Carex globularis with significant response to temperature, illustrating a pair of non-overlapping confidence intervals (dashed and dotted line) associated with a pair of temperature sum values.
If the response to temperature was significant in both *temperature-only* and *all-predictors models*, we further checked whether the temperature response was consistent between the two models. This too was assessed on the basis of the estimated 95% confidence intervals by checking whether the pattern of high and low responses that was found significant in the *temperature-only model* can be reproduced within the confidence intervals of the all-predictors model. To specify how this was implemented, let us define $T_+$ as the value of effective temperature sum that maximizes $l_1(T)$, the lower limit of the confidence interval in the temperature-only model, and $T_-$ as the value that minimizes $u_1(T)$. Furthermore, let $L$ denote the set of temperature sum values $T$ with “significantly low MPA”, $u_1(T) < l_1(T_+)$, and $H$ the set with “significantly high MPA”, $l_1(T) < u_1(T_-)$. Then the responses were defined to be consistent, if the following conditions were satisfied by the confidence intervals $[l_2(T), u_2(T)]$ for the partial effect of effective temperature sum in all-predictors model (Fig. A2-2):

$$l_2(T) < u_2(T_-), \text{ for all } T \in L,$$

$$u_2(T) > l_2(T_+), \text{ for all } T \in H.$$
Figure A2-2. Examples with consistent and inconsistent response to temperature between temperature-only and all-predictors models. a) Temperature-only model for *Epilobium angustifolium*. $T_\ast$ maximizes $l_1(T)$, the lower limit of the 95% confidence interval. $T_\ast$, the value that minimizes $u_1(T)$ is the left-hand end of the range of effective temperature sums included in our data. The x-range of the dashed line segment shows the set $L$ of temperature sum values with “significantly low MPA”; its y-level is the upper limit in the criterion $L=\{T: u_1(T) < l_1(T)\}$. Similarly, the dotted line segment illustrates $H$, the set with “significantly high MPA”. b) Partial effect of effective temperature sum in all-predictors model of *E. angustifolium*. The x-ranges of the dashed and dotted line segments are the same as in a), but their y-levels were determined from the all-predictors model to illustrate the limits $u_2(T)$ and $l_2(T)$ in our criteria for consistency. Models shown in a) and b) are consistent, because $l_2(T)$ is completely below the dashed line and $u_2(T)$ completely above the dotted line within the range of these segments. As a result, such a partial response fits within the confidence intervals of the all-predictors model, where MPA is lower at all $T \in L$ than at $T_\ast$ and greater at all $T \in H$ than at $T_\ast$. c) and d) are as a) and b), but for *Vaccinium*.
myrtillus.; $T$ is again the smallest effective temperature sum. The models shown in c) and d) are not consistent, because a response fitting within the confidence intervals can’t have MPA lower than that at $T$ at any $T$ in the lower part of $L$, and it can have MPA higher than that at $T$ only in a very small part of $H$. 
Appendix 3: Quantile regression models at 95% on the response of species abundance to effective temperature sum for all 25 species of understory boreal vegetation considered in the study. Models were developed using data of 868 nation-wide plots sampled in Finland in 1985 and climate data from 1961 to 1985. Abundance of species is measured as percentage cover. Temperature-only models (blue) include only effective temperature sum as predictor, while all-predictors models (red) analyze the partial effect of effective temperature sum on abundance of species, in models that also include cumulative precipitation, soil texture, soil fertility, stand basal area and proportion of deciduous tree species as predictors. All variables are included with linear and quadratic terms, except for the factor soil fertility. Confidence intervals at 95% are shown with a shaded area.
Graphs showing the abundance (% cover) of different plant species as a function of effective temperature sum (°C). The species include:

1. *Epilobium angustifolium*
2. *Hylocomium splendens*
3. *Linnaea borealis*
4. *Luzula pilosa*
5. *Maianthemum bifolium*
6. *Melampyrum pratense*

Each graph compares temperature-only model and all-predictors model.
**Appendix 4**: Values $L_{1,sp}$ and $L_{2,sp}$ of the check-loss-function based measure of predictive performance of *temperature-only* and *all-predictors models*, respectively, for all 25 species (sp) of understory boreal vegetation considered in the study. Green color refers to species selected for forecasting, red to those excluded from forecasts due to insignificance or inconsistency of temperature responses in the two models. See values in Appendix 1.
**Appendix 5:** Maximum potential abundance of 15 understory plant species modeled from 868 plots and its spatial distribution predicted in Finland for 1985 and 2041-2070 under IPCC scenario A1B. For each species, the graph on the left represents the relationship of species abundance with effective temperature sum along 868 plots of the Finnish National Forest Inventory in 1985. The blue line shows the maximum potential abundance predicted at each point in the temperature gradient by the 95% quantile regression model that includes the linear and quadratic terms of effective temperature sum as predictors (*temperature-only model*). Blue shaded areas indicate confidence intervals at 95%. The 868 sample sites are represented with black transparent points, so that darker regions indicate plot superposition. The maps show the spatial distribution of the maximum potential abundance predicted by these models for temperatures in 1985 (central panel) and for temperatures forecasted for 2041-2070 under IPCC scenario A1B (right panel). No extrapolation was attempted for temperatures beyond those in the training model of 1985, so areas with novel climates or not represented by sampling plots are in grey. Solid, dashed and dotted lines in graphs indicate 75%, 50% and 25% maximum abundance values, respectively. The same lines in maps represent the latitudinal limits of these abundance values. These limits are not represented when the spotted value falls outside or at the latitudinal limits of the study area. The northern limits (i.e., the maximum latitude at which these abundance values are found) are represented for southern species (*Calamagrostis arundinacea, Dicranum polysetum, Maianthemum bifolium and Tristentis europaea*), while the southern limits (i.e., the minimum latitude at which these abundance values are found) are represented for northern species (*Carex globularis, Cladina rangiferina, Dicranum scoparium, Epilobium angustifolium, Hylocomium splendens, Pleurozium schreberi, Pohlia nutans, Polytrichum juniperum, Solidago virgaurea, Vaccinium uliginosum, Vaccinium vitis-idaea*). These 15 species represent those with significant responses to effective temperature sum in temperature-only models that are consistent when including other environmental predictors in the model (*all-predictors models*, see Appendix 1-3). Species are ordered by functional group.
Dwarf shrubs

Herbs
Graminoids
Bryophytes
Lichens
Appendix 6: Latitudinal shift of species maximum potential abundance predicted from 1985 to 2040-2070 in Finland, under IPCC scenario A1B. Results are shown for 15 species with significant and consistent responses to effective temperature sum in temperature-only models and all-predictors models (see Appendix 1-3). It is shown the latitudinal shift in different points of the distribution: specifically, for the values corresponding to 75%, 50% and 25% the maximum absolute value of maximum potential abundance (MPA) of the specie. These limits are not represented when the spotted value falls outside or at the latitudinal limit of the study area to avoid misinterpretation. Species are classified as southern or northern depending on the location of their abundance distribution across the country. For southern species, the latitudinal shift is calculated for their northern limits (i.e., the maximum latitude at which these 75%, 50%, 25% MAP abundance values are found; “northern” in table). For northern species, the latitudinal shift is calculated for their southern limits (i.e., the minimum latitude at which these abundance values are found; “southern” in table). Finally, the average shift is calculated as the mean between the three values, when all these three are available.

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<th>Shift 50% MPA (Km)</th>
<th>Shift 75% MPA (Km)</th>
<th>Mean shift (Km)</th>
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**Appendix 7:** Quantile regression models at 95% of the partial effect of different environmental factors on the abundance of the 25 species of understory boreal vegetation considered in the study. Models were developed using data of 868 nation-wide plots sampled in Finland in 1985 and climate data from 1961 to 1985. Abundance of species is measured as percentage cover. The partial effect of each variable is controlled by the average effect of all other variables in *all-predictors models* (see Appendix 3). All variables are included with linear and quadratic terms, except for the factor soil fertility, which is only included in its simple term. Confidence intervals at 95% are shown with a shaded area. Temp. sum: effective temperature sum (°C), Cumul. precip.: cumulative precipitation (mm yr⁻¹), Basal area: stand basal area (ha⁻¹), Soil texture: soil texture (index 1-10, from bare rock to grain size <0.002 mm), Soil fertil.: soil fertility (index 1-4, from high to low fertility), Decid. trees: proportion of deciduous tree species (% of tree basal area).
Maianthemum bifolium

Melampyrum pratense

Pleurozium schreberi